Taxonomy and Biology of Egg Parasitoids of Auchenorrhyncha of Economic Importance in Taiwan and Adjacent Countries, and of Proconiine Sharpshooters in the New World

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ABSTRACT

An overview of the taxonomic and biological studies on the egg parasitoids (Hymenoptera: Mymaridae and Trichogrammatidae) of Auchenorrhyncha (Hemiptera) of economic importance in Taiwan (Republic of China) and adjacent countries is given, and their current status is discussed. Also provided is a summary of taxonomy and biology of the hymenopteran egg parasitoids of various Proconiini (Hemiptera: Cicadellidae: Cicadellinae), particularly the glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar), in the New World, with references to its biological control in the non-native range.

Keywords: Cicadellidae, Delphacidae, Proconiini, *Homalodisca vitripennis*, vector, Aphelinidae, Mymaridae, Trichogrammatidae, egg parasitoid, biological control.

INTRODUCTION

Most common egg parasitoids of Auchenorrhyncha (Hemiptera) belong to two families of Hymenoptera, Mymaridae and Trichogrammatidae (superfamily Chalcidoidea). Worldwide, they are largely responsible for the natural control of leafhopper (Cicadellidae), planthopper (Delphacidae), and treehopper (Membracidae) species, including economically important pests. Therefore knowledge of their taxonomy (for identification) and biology is very important for biological control, ecological, and biodiversity studies. Provided herein is an overview of the history and current status of the taxonomy and biology of these two groups of egg parasitoids in Taiwan (Republic of

China) and the adjacent countries. Due to the recent identification of the phytopathogenic bacterium *Xylella fastidiosa* in the vineyards of Taiwan [84], which causes Pierce's disease of grapevines (the first such record in Asia), a summary of the known egg parasitoids of the proconiine sharpshooter leafhoppers (its vectors) in the New World is also given. Information on egg parasitoids of leafhoppers from the tribe Cicadellini, also from the subfamily Cicadellinae, is scarce globally. Cicadellini contain several known vector species for *X. fastidiosa* in the USA, where their eggs are parasitized by a few *Gonatocerus* spp. and also a *Polynema* sp. [5, 6, 125]; *Kolla paulula* (Walker) is a potential vector of *X. fastidiosa* [82] and a common cicadellid species in Taiwan [84]. In Japan and elsewhere, *Gonatocerus longicornis* Nees ab Esenbeck and several *Anagrus* spp. are known as egg parasitoids of *Cicadella viridis* (Linnaeus) [21, 107].

Taxonomy and biology of egg parasitoids of Auchenorrhyncha of economic importance in Taiwan and adjacent countries

Biogeographically, the fauna of Taiwan is primarily Oriental, although at high altitudes it arguably fits more in the Palaearctic ecozone, with some Himalayan elements. The faunas of the adjacent countries are either within the Oriental (the Philippines) or Palaearctic (Republic of Korea), or both (People's Republic of China and Japan) ecozones, although most of the latter country, except for the southern Ryukyu Islands, has a Palaearctic fauna as does the more remote Russian Far East. The entire region also has a number of cosmopolitan or Old World taxa, some transpacific elements (genera and species) that occur from Australasia (Queensland) to the eastern Palaearctic (Russian Far East and northern Japan), endemic, relict, and possibly a few unintentionally introduced species. Historically, dealing with such diversity has been challenging for taxonomists of parasitic Hymenoptera, particularly due to the fact that many species of egg parasitoids of Auchenorrhyncha, including economically important ones, are often widespread in distribution. A "single country" focal approach (rather than regional or hemisphere, or global) to parasitoid taxonomy thus has been particularly problematic and detrimental for these groups of insects: to be able to correctly identify a parasitoid from one country in east and southeast Asia a taxonomist needs to have knowledge, at a minimum, of the congeneric taxa from the northern Australasian, Oriental, and Palaearctic regions. That includes availability of comparative, identified material and access to type specimens, scientific literature, etc. While generic identifications of most Mymaridae and Trichogrammatidae in the region

are generally relatively easily available, species identifications are still a major problem [96]. Expensive and time-consuming special preservation and mounting techniques, such as microscopic slides in Canada balsam, are usually required to be able to identify any mymarid or trichogrammatid to species based on morphology. Overall, taxonomic studies on the diversity of egg parasitoids lag significantly compared to those of leafhoppers and other Auchenorrhyncha; the latter have seen considerable progress recently, especially in the People's Republic of China. However, unlike their taxonomy, the natural history of most leafhoppers and other groups is still poorly known, besides a few species that are agricultural pests, primarily of rice. Despite numerous publications on mymarid and trichogrammatid egg parasitoids of the rice leafhoppers and planthoppers in Asia (reviewed by Gurr *et al*. [28] for the planthopper hosts), their identifications, particularly those in the fairyfly genera *Anagrus* Haliday and *Gonatocerus* Nees ab Esenbeck and trichogrammatid genera *Oligosita* Walker and *Paracentrobia* Howard, are generally unreliable and many, particularly pre-2000s, are incorrect or outdated. *Aprostocetus* (*Ootetrastichus*) spp. (Eulophidae) are not covered in this review because they act more as egg predators than parasitoids of various Auchenorrhyncha.

Keys and taxonomic revisions of regional importance.

These are unfortunately few, but can be helpful to recognize genera: Subba Rao and Hayat [85] and Triapitsyn and Huber [116] for Mymaridae, and Doutt and Viggiani [22] for Trichogrammatidae. For relevant records and recognition of species in some genera of Mymaridae: Chiappini *et al*. [19], Triapitsyn [93], Triapitsyn and Beardsley [103], and Triapitsyn and Berezovskiy [107] for *Anagrus*; Triapitsyn [100] for *Ooctonus* Haliday; Triapitsyn [102] for *Gonatocerus*; Triapitsyn and Berezovskiy [104] for *Mymar* Curtis; Triapitsyn and Berezovskiy [109] for *Acmopolynema* Ogloblin, with the description of *A. orchidea* Triapitsyn and Berezovskiy from Orchid Island (Lan Yü), Taiwan; Huber [34] for *Chaetomymar* Ogloblin (a synonym of *Palaeoneura* Waterhouse); Huber and Fidalgo [35] for *Stephanodes* Enock. Owen [72] revised the world species of *Ufens* Girault (Trichogrammatidae).

Taxonomic and biological studies on egg parasitoids of Auchenorrhyncha, listed by country. TAIWAN (REPUBLIC OF CHINA): Taguchi [87, 88, 89, 90] published on taxonomy of *Himopolynema* Taguchi, *Mymar*, *Palaeoneura*, and *Stephanodes*,

which contain descriptions of several new species. Unfortunately, the entire Hidenari Taguchi collection (originally in Ehime University, Matsuyama, Japan) of Mymaridae is lost, including the types. Lin [43], Miura *et al*. [64], and Chen [16] reported on egg parasitoids of the rice leafhoppers and planthoppers; Chen and Yu [17] studied *Anagrus* egg parasitoids of brown rice planthopper, *Nilaparvata lugens* (Stål) (Delphacidae); Chu and Hirashima [20] summarized the earlier Taiwanese literature on the natural enemies of rice leafhoppers and planthoppers. PEOPLE'S REPUBLIC OF CHINA: Lin and Xu [48] keyed the genera of Mymaridae; Lin [44, 46] and Guo *et al*. [27] reported on the classification of Mymaridae and Trichogrammatidae and their use in biological control; Pang and Wang [73] and Chiappini and Lin [18] reviewed the Chinese species of *Anagrus*; Xu and Lin [128] published on *Acmopolynema*; Zhang *et al*. [130] reported on *Stethynium* Enock. A taxonomic revision of the Chinese Trichogrammatidae by Lin [45] contains keys to the species of the genera that are known as egg parasitoids of Auchenorrhyncha; also important are studies by Hu and Lin [30, 31, 32] and Hu *et al*. [33] on several trichogrammatid genera. Publications on egg parasitoids of the rice leafhoppers and planthoppers, mainly on *Anagrus* spp., in mainland China are so numerous that it is impossible to list them here; those on egg parasitoids of Delphacidae were reviewed by Gurr *et al.* [28]. Mao *et al.* [54] reported on egg parasitoids of *Empoasca vitis* (Goethe); *Hispidophila sophoniae* Lin and Lin and *Ufens rimatus* Lin (Trichogrammatidae) were among the complex of 11 species of mymarid, trichogrammatid, and aphelinid egg parasitoids of *Sophonia* spp. (Cicadellidae) in southern China [47, 55]. JAPAN: Doutt [21] published on some egg parasitoids of leafhoppers; Taguchi [86, 87, 88, 89, 90] on *Acmopolynema*, *Himopolynema*, *Mymar*, *Palaeoneura*, *Polynema* Haliday, and *Stephanodes*; Sahad [79] and Sahad and Hirashima [81] on *Anagrus* and *Gonatocerus*. *Himopolynema hishimonus* Taguchi is a parasitoid of *Hishimonus sellatus* (Uhler) (Cicadellidae) [89]. *Mymar taprobanicum* Ward was reported from an egg of *Delphacodes striatella* (Fallén) (Delphacidae) [87]. Chantarasa-ard *et al.* [13, 14, 15], Miura [56, 57, 58, 59], Miura and Miura [60, 61], Miura and Yano [62, 63], Otake [67, 68, 69, 70, 71], Sahad [77, 78, 80], and Sahad and Hirashima [81] studied biology of *Anagrus* spp. and *Gonatocerus* spp. as well as that of *Paracentrobia andoi* (Ishii) (Trichogrammatidae). REPUBLIC OF KOREA: Chang [11], Kim [39], Kim *et al.* [40], Yeo *et al.* [129], and Chang *et al.* [12] reported on *Anagrus* spp. and *P. andoi* egg parasitoids of the rice leafhoppers and planthoppers. PHILIPPINES: Chandra [8, 9], Chandra and Dyck [10], and Tran [92] studied *Anagrus* parasitoids of the rice leafhoppers

and planthoppers. RUSSIA: in the Russian Far East, taxonomic studies on Mymaridae were conducted by Berezovskiy and Triapitsyn [2], Triapitsyn [97], and Triapitsyn and Berezovskiy [104, 105, 106, 108], and on Trichogrammatidae by Fursov [23].

Looking ahead. There are several taxonomic challenges that can be identified as priority projects in the region for future studies, as follows: 1) Figuring out the true taxonomic identity of *Anagrus nilaparvatae* Pang and Wang, a common and economically important egg parasitoid of *N. lugens* and other rice pests in the Oriental and eastern Palaearctic regions. As noted by Triapitsyn and Berezovskiy [107], *A. nilaparvatae* is morphologically practically indistinguishable from the common, widespread, polyphagous Palaearctic species *A. incarnatus* Haliday. Collections of reared specimens of both taxa should be made from various hosts and locations throughout their ranges, including the type localities, and a combination of morphometric and molecular studies, and also of cross-breeding experiments, should be considered to solve this problem. 2) Taxonomy of other egg parasitoids (Mymaridae and Trichogrammatidae) of the rice leafhoppers and planthoppers in Asia needs to be revised including the use of molecular methods to distinguish cryptic species. 3) Taxonomic revisions of the most important genera which contain known egg parasitoids of various Auchenorrhyncha, for the entire Oriental and adjacent regions: *Anagrus*, *Gonatocerus* (Oriental and Australasian regions), *Himopolynema*, and *Polynema* (Mymaridae), as well as *Aphelinoidea* Girault, *Oligosita*, *Paracentrobia*, and *Pseudoligosita* Girault (Trichogrammatidae). Such revisions would be particularly useful for identifications of the natural enemies of leafhopper, planthopper, and other agricultural pests. 4) Establishing host-parasitoid associations for the most common and economically important species of leafhoppers (particularly from the tribe Cicadellini), planthoppers, and other Auchenorrhyncha, based on thorough rearings (including using sentinel eggs) and taxonomic identifications of both the host and parasitoid(s). The recent, notable advances in leafhopper taxonomy (but not biology, knowledge of which is often lacking), particularly in People's Republic of China, would facilitate such studies.

Taxonomy and biology of egg parasitoids of Proconiini in the New World and beyond

Proconiine sharpshooters belong to the New World cicadelline leafhopper tribe Proconiini (Hemiptera: Cicadellidae: Cicadellinae). The most notorious is the

glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar), a vector of plant diseases caused by the phytopathogenic bacterium *Xylella fastidiosa* [3]. The glassy-winged sharpshooter is a self-introduced pest in California from the southeastern USA. Turner and Pollard [125] provided a brief overview of proconiine sharpshooter egg parasitoids (Mymaridae and Trichogrammatidae) in Georgia. For a long time this was the only available publication on this group of natural enemies, which more recently has been shown to be amazingly diverse; almost every sharpshooter species has been found, upon closer examination, to have a complex of associated egg parasitoids. Establishment of *H. vitripennis* in California in the 1990s, later in Hawaii, USA and French Polynesia, and even more recently in Easter Island (Chile) [76] prompted interest in proconiine sharpshooter investigations, including studies of their egg parasitoids in North America [111, 115, 120, 122, 123], mainly for classical biological control purposes [65, 66, 75, 76, 113, 114]. An overview of the genera in several families of Chalcidoidea (Hymenoptera) containing known egg parasitoids of Proconiini follows.

APHELINIDAE

Centrodora Förster: Species of this genus appear to be more polyphagous egg parasitoids of some Hemiptera and are very difficult to identify. The two species reared from eggs of Proconiini remain undetermined: one *Centrodora* sp. from Tahiti and Moorea Islands, French Polynesia is a parasitoid of the non-native *H. vitripennis* [26]; the other *Centrodora* sp. was reared in Argentina from eggs of *Tapajosa rubromarginata* (Signoret) and *Tretogonia notatifrons* Melichar (G. A. Logarzo and S. V. Triapitsyn, unpublished).

MYMARIDAE

Acmopolynema: One species of this genus, *A. sema* Schauff, was reared in Florida and Georgia, USA, from eggs of *Homalodisca insolita* (Walker) [115].

Anagrus: Four species of this genus have been recorded as egg parasitoids of Proconiini: *A. epos* Girault in Minnesota, USA, a gregarious parasitoid of *Cuerna fenestella* Hamilton [29, 99], which was mass-reared and released without much success in California, USA against *H. vitripennis* [7, 42], where its host specificity and other biological traits were studied by Krugner *et al.* [41]; *A. stethynioides* Triapitsyn, an occasional and poorly known parasitoid of *H. vitripennis* in Texas, USA [99], which is also known from several countries in Central and South America [95]; *A. breviphragma*

Soyka from *Dechacona missionum* (Berg) in Argentina [51]; and an *Anagrus* sp., which was reared in Tahiti Island, French Polynesia, from an egg mass of the invasive *H. vitripennis* [26].

Gonatocerus: This large and common genus contains many species that are known as egg parasitoids of various Proconiini, including those used in the biological control program against *H. vitripennis* in California [7], as summarized by Triapitsyn [99] for the Nearctic region and Triapitsyn *et al.* [117] for the Neotropical region. Details on their diversity, taxonomy, host associations and other biological traits are therefore omitted for brevity: these are readily available and too numerous to fit in this communication. All are solitary egg parasitoids, producing one wasp per host egg, except for *G. fasciatus* Girault which is a gregarious parasitoid [121]. Biology of several species of *Gonatocerus* was thoroughly studied [36, 37, 38, 83, 126]. They do not appear to be too host specific but rather are usually able to attack eggs of at least several genera and species of Proconiini [4, 49, 53]. All of them belong to the subgenus *G.* (*Cosmocomoidea* Howard), which also contains a large number of undescribed species from Central and South America which are likely egg parasitoids of Proconiini [94, 117], thus suggesting apparent co-evolution. Triapitsyn [101] reported the following species of *Gonatocerus* from eggs of *H. vitripennis* in California: *G. ashmeadi* Girault, *G. fasciatus* (intentionally introduced), *G. incomptus* Huber, *G. morgani* Triapitsyn, *G. morrilli* (Howard) (intentionally introduced), *G. novifasciatus* Girault, *G. triguttatus* Girault (intentionally introduced), and *G. walkerjonesi* Triapitsyn. The southern and southeastern USA strains of *G. ashmeadi* were released in California against *H. vitripennis* [65, 76]. *Gonatocerus ashmeadi* was found self-introduced in Oahu Island, Hawaii (USA), where it provides a good control of *H. vitripennis* [99]; it was intentionally and successfully introduced into French Polynesia for very effective biological control against *H. vitripennis* [24, 25]. It was also found self-introduced in Easter Island [99]. Paradell *et al.* [74] summarized the known egg parasitoids of Proconiini in Argentina, the majority of which are *Gonatocerus* species described or revised taxonomically by Triapitsyn *et al.* [117, 118, 119, 124]; *T. rubromarginata* is the most thoroughly studied host of many of these parasitoids.

Palaeoneura: One undetermined species of this genus was reared in Tahiti Island from eggs of *H. vitripennis* [26].

Polynema: An undescribed species of *P.* (*Doriclytus*) sp. was reared in California, USA from eggs of *H. vitripennis*; it is only an occasional parasitoid of this host [101].

One or two other *P.* (*Doriclytus*) spp. were reared in Argentina from sentinel eggs of *T. rubromarginata* (G. A. Logarzo and S. V. Triapitsyn, unpublished).

TRICHOGRAMMATIDAE

Members of several genera are gregarious egg parasitoids of various Proconiini, all native to the New World [98]; trichogrammatids are generally relatively more common on grassy vegetation and in dry habitats.

Burksiella De Santis: *Burksiella spirita* (Girault) is a common egg parasitoid of *H. vitripennis* and also of *Oncometopia orbona* (Fabricius) in the southeastern USA [98, 101]; a related form, which may or may not belong to this species, was reared in Montana, USA, from eggs of *Cuerna sayi* Nielson [112]. One or two different, undetermined species of *Burksiella* spp. were reported from eggs of *Homalodisca liturata* Ball in Mexico [110]. *Burksiella platensis* (De Santis) is known from eggs of *T. rubromarginata* in Argentina [98].

Ittys Girault: One undescribed species of this genus was reported from eggs of *H. liturata* in Mexico [110].

Oligosita: An *Oligosita* sp., possibly *O. americana* Girault, was reared in Georgia, USA from eggs of *Homalodisca insolita* (Walker) [98, 125]. Undetermined *Oligosita* spp. were also reared from eggs of two species of Proconiini in Argentina [74]; however, at least one of these is a member of *Pseudoligosita* [110].

Paracentrobia: *Paracentrobia acuminata* (Ashmead) was reared in Florida and Georgia, USA from eggs of *Cuerna costalis* (Fabricius), *H. insolita,* and *H. vitripennis* [91, 98, 125]. Also *P. americana* (Girault) is a parasitoid of *H. insolita* in Florida [91]. In Argentina, *P. tapajosae* Viggiani is known from eggs of *T. rubromarginata* [127], who studied biology of the parasitoid. Undetermined *Paracentrobia* spp. were also reared from eggs of three other species of Proconiini in Argentina [74].

Pseudoligosita: Two species of this genus were reared from eggs of Proconiini: *P. plebeia* (Perkins) from *H. liturata* in Mexico [101, 110] and also from eggs of *T. rubromarginata* in Argentina [110]; and an undetermined and apparently undescribed *Pseudoligosita* sp. from eggs of *H. vitripennis* in California [101]. Biological traits of *P. plebeia*, which was reared under quarantine conditions in California on eggs of *H. vitripennis*, were reported by Triapitsyn and Bernal [110] and Lytle *et al.* [52].

Ufens: *Ufens ceratus* Owen and *U. principalis* Owen are common egg parasitoids of *H. liturata* and *H. vitripennis* in Mexico and USA [1, 101, 110], and *U.*

ceratus is also known from *Oncometopia clarior* (Walker) in Mexico [111] (as *Ufens* sp.). *Ufens niger* (Ashmead) was reported from eggs of *C. costalis* and *Homalodisca* sp. [98, 125].

Zagella Girault: The sharpshooter *T. rubromarginata* is a known host of *Z. delicata* De Santis, the biology of which was reported by Logarzo *et al.* [50]. Undetermined *Zagella* spp. were also reared from eggs of three other species of Proconiini in Argentina [74].

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